

5 **ON-CHIP INDUCTOR HAVING IMPROVED QUALITY FACTOR AND METHOD
OF MANUFACTURE THEREOF**

TECHNICAL FIELD OF THE INVENTION

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This invention relates generally to integrated circuits and more particularly to on-chip inductors.

BACKGROUND OF THE INVENTION

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Integrated circuits (IC's) are known to include a substrate, one or more dielectric layers on the substrate, and one or more metal layers supported by a corresponding dielectric layer. The metal layers are fabricated in such a way to produce on-chip components such as resistors, transistors, capacitors, inductors, et cetera. How an on-chip component is fabricated, as well as the number of dielectric layers and metal layers, minimum and maximum metal track sizes, and spacing between metal tracks, are dictated by the technology used and corresponding foundry rules governing the fabrication of integrated circuits using such technology.

For example, CMOS technology is readily used for cost effective integrated circuits. Foundries that manufacture CMOS integrated circuits provide rules governing the number of dielectric layers and metal layers, minimum and maximum metal track sizes, spacing between the metal tracks, fabrication options, and other aspects of integrated circuit production. The fabrication options include adding

a P-well layer, adding a field oxide layer, adding a poly-shield, et cetera.

It has become conventional wisdom, (i.e., a de-facto
5 standard) among on-chip inductor designers that the quality
factor (i.e., the measure of a component's, or circuit's,
ability to provide a large output at resonant frequency and
the frequency selectivity of the component or circuit) is
maximized by including a poly-shield with a P-well layer
10 and a field oxide layer. By designing 8 to 10 nano Henry
on-chip inductor in accordance with conventional wisdom, a
quality factor of about 8.07 to 8.70 can be obtained at 2.4
gigahertz. While such inductors may be acceptable for some
applications, improving the quality factor of on-chip
15 inductors improves performance in such applications and
allows on-chip inductors to be used in many other
applications currently beyond the reach of conventional on-
chip inductors.

20 Therefore, a need exists for an on-chip inductor that
has an improved quality factor with respect to current on-
chip inductors and a need exists for a method of
manufacture thereof.

25 SUMMARY OF THE INVENTION

The on-chip inductor disclosed herein substantially
meets these needs and others. An on-chip inductor, in
accordance with the present invention, consists of at least
30 one dielectric layer, at least one conductive winding on
the at least one dielectric layer and a P-well layer having
a major surface that is parallel to a major surface of the

dielectric layer. The on-chip inductor may be expanded to include a plurality of conductive windings on one or more dielectric layers. In addition, the on-chip inductor may be expanded to further include a field oxide layer. In
5 addition, the on-chip inductor may include a center tap to produce a differential inductor and/or may include a 2nd winding to produce an on-chip transformer. The on-chip inductor, however, does not include a poly-shield.

10 An alternate embodiment of an on-chip inductor includes at least one dielectric layer, at least one conductive winding on the at least one dielectric layer and a field oxide layer that has a major surface parallel with the major surface of the dielectric layer. In this
15 embodiment, the on-chip inductor may be expanded to include a P-well layer. In addition, the conductive winding may include several turns per layer and may include several layers. In addition, the on-chip inductor may include a center tap to produce a differential inductor and/or may
20 include a 2nd winding to produce an on-chip transformer. The on-chip inductor, however, does not include a poly-shield.

25 In another embodiment of an on-chip inductor in accordance with the present invention, the on-chip inductor includes at least one dielectric layer, at least one conductive winding on the at least one dielectric layer and a poly silicon layer (i.e., a poly shield layer) that has a
30 major surface that is parallel to the major surface of the dielectric layer. In this embodiment of the on-chip inductor, the on-chip inductor does not include a P-well

layer or a field oxide layer. As with the other
embodiments, the on-chip inductor may be expanded to
include a 2nd winding to produce an on-chip transformer
and/or may include a center tap to produce a differential
5 inductor.

Each of the embodiments of the on-chip inductor may be
fabricated by creating at least one dielectric layer,
creating at least one conductive winding on the at least
10 one dielectric layer and creating either a P-well layer,
field oxide layer or poly-silicon layer having a major
surface parallel to a major surface of the dielectric
layer.

15 BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A and 1B illustrate a top and side view of an
on-chip inductor in accordance with the present invention;

20 Figures 2A and 2B illustrate an alternate embodiment
of an on-chip inductor in accordance with the present
invention;

Figures 3A and 3B illustrate another embodiment of an
25 on-chip inductor in accordance with the present invention;

Figures 4A and 4B illustrate yet another embodiment of
an on-chip inductor in accordance with the present
invention;

30 Figure 5 illustrates a further embodiment of an on-
chip inductor in accordance with the present invention;

Figures 6A and 6B illustrate a differential inductor in accordance with the present invention;

5 Figures 7A - 7C illustrate an on-chip transformer in accordance with the present invention;

Figures 8A and 8B illustrate a still further embodiment of an on-chip inductor in accordance with the
10 present invention; and

Figure 9 illustrates a logic diagram of a method of manufacture of an on-chip inductor in accordance with the present invention.

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DETAIL DESCRIPTION OF A PREFERRED EMBODIMENT

Figures 1A and 1B illustrate a top and side view of an on-chip inductor 10 that includes a winding 12 created on a
20 dielectric layer 14. A P-well layer 13 and a substrate 16 support the dielectric layer 14. As shown, a major surface 20 of the dielectric layer 14 is substantially parallel to a major surface 22 of P-well 13. In this embodiment of the on-chip inductor 10, a poly silicon layer (i.e., a poly-shield) is not included. By including a P-well layer with the absence of a poly-shield, quality factors for an 8-10 nano Henry inductor at 2.4 gigahertz of at least 10, which corresponds to a Q factor improvement of at least 15% and more typically of 25% in comparison to a similar inductor
25 having both a poly shield and a P-well.
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As one of average skill in the art will appreciate, the on-chip inductor 10 of Figure 1 as well as the other on-chip inductors and transformers described throughout the remaining figures, may be implemented using CMOS

5 technology, gallium arsenide, silicon germanium, or any other type of technology used to implement integrated circuits.

Figures 2A and 2B illustrate a top and side view of
 10 on-chip inductor 25 that includes winding 12 created on dielectric layer 14. The dielectric layer 14 is supported by a field oxide layer 32 and substrate 16. Major surface 20 of dielectric layer 14 is parallel to major surface 22 of field oxide layer 32. In this embodiment of on-chip
 15 inductor 25, a poly-silicon layer is not included. As with the inclusion of a P-well layer with the exclusion of a poly-silicon, the inclusion of a field oxide layer with the exclusion of a poly-silicon, improves the quality factor by at least 15% in comparison to including both.

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Figures 3A and 3B illustrate a top and side view of on-chip inductor 30 that includes winding 12 created on dielectric layer 14. Dielectric layer 14 is supported by a field oxide layer 32, a P-well layer 18 and substrate 16.
 25 A major surface 30 of dielectric layer 14 is parallel to major surface 34, a field oxide layer 32 and major surface 22 of P-well 18. In this embodiment of the on-chip inductor 30, a field oxide layer 32 and P-well layer are included but a poly-silicon layer is omitted. By including
 30 both a P-well layer and field oxide layer as opposed to including only one of the layers, the quality factor is

further increased in comparison to including the poly shield with the P-well and field oxide layer.

Figures 4A and 4B illustrate an on-chip inductor 40 that includes a spiral winding 42, metal bridges 44, dielectric layer 14, and dielectric layer 46. The spiral winding 42 is created on dielectric layer 14 while the metal bridges 44 are created on dielectric layer 46. The on-chip inductor 40 may include a P-well layer 18 and/or a field oxide layer 32. The entire structure is supported by substrate 16. The major surfaces of the dielectric layer 14 are substantially parallel to the major surfaces of the P-well 18 and/or field oxide layer 32. The on-chip inductor 40, however, does not include a poly-shield.

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Figure 5 illustrates a side view of an on-chip inductor that has windings 50 and 52 on multiple dielectric layers 12, 14 and 58. The on-chip inductor further includes a P-well layer 18 and/or a field oxide layer 32 supported by substrate 16. Windings 50 and 52 may be single windings or spiral windings and may be connected in serial or parallel fashion. The on-chip inductor, however, does not include a poly-shield.

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Figures 6A and 6B illustrate a top and side view of a differential inductor 60 that includes winding 12, center tap 62 created on dielectric layer 14. The differential inductor 60 also includes a P-well layer 18 and/or a field oxide layer 32 that is supported by substrate 16. Note that the winding 12 may include one or more turns on one or more dielectric layers. Further note that the differential inductor 60 does not include a poly-silicon.

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Figures 7A - 7C illustrate an on-chip transformer 70 that includes winding 12 on dielectric layer 14, secondary windings 74 on dielectric layer 72 a P-well layer 18 and/or a field oxide layer 32 on substrate 16. The winding 12 may act as a primary winding for secondary winding 74. Each of the windings 12 and 74 may include multiple turns for dielectric layer and/or may include turns on multiple dielectric layers. The on-chip transformer 70 does not include a poly-silicon layer, which provides a poly-shield. As such, the quality factor of the windings 12 and 74 is increased in comparison to current on-chip inductors that include both a poly-shield and a P-well or field oxide layer.

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Figures 8A and 8B illustrate an on-chip inductor 80 that includes winding 12 on dielectric layer 14 and includes a poly-silicon shield 82 on substrate 16. In this embodiment, a field oxide layer and P-well layer are omitted. By including only a poly-silicon shield and not a P-well or field oxide layer, the quality factor, in comparison to including a poly-silicon with a P-well and/or with a field oxide layer is increased by 10-20%.

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As one of average skill in the art will appreciate, the on-chip inductor 80 may have a multi-turn winding 12, may have winding 12 on multiple dielectric layers and/or may include a secondary winding to produce an on-chip transformer. In addition, the on-chip inductor 80 may include a center tap to produce a differential on-chip inductor.

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Figure 9 illustrates a logic diagram for manufacturing an on-chip inductor. The process begins at Step 90 where at least one dielectric layer is created on a substrate. The process then proceeds to Step 92 where at least one
5 conductive winding is created on at least one dielectric layer. The conductive winding may include one or more turns on one or more dielectric layers to produce an on-chip inductor. In addition, the conductive winding may have a center tap to produce a differential inductor. In
10 addition, a 2nd conductive winding may be produced on a 2nd dielectric layer to produce an on-chip transformer.

The process then proceeds to Step 94 where a P-well and/or a field oxide layer are created or a poly-silicon
15 shield is created on a substrate. As such, the on-chip inductor will be created with a P-well layer and/or a field oxide layer exclusive of a poly-silicon shield or created with a poly-silicon shield exclusive of a P-well layer and a field oxide layer. As one of average skill in the art
20 will appreciate, when multiple metal layers are fabricated, the fabrication process creates one dielectric layer, then a corresponding metal layer, which repeats for each metal layer desired. As one of average skill in the art will further appreciate, the fabrication steps may vary from the
25 ones illustrated.

The preceding discussion has presented an on-chip inductor that has an improved quality factor and a method of manufacture thereof. By exclusively including a poly-
30 silicon shield or a P-well and/or field oxide layer, the quality factor of on-chip inductors and on-chip transformers is improved. As one of average skill in the

art will appreciate, other embodiments may be derived from the teachings of the present invention, without deviating from the scope of the claims.